

MAP PROJECTIONS AND VISUALIZATION OF NAVIGATIONAL PATHS IN ELECTRONIC CHART SYSTEMS

Athanasios PALLIKARIS^[1] and Lysandros TSOULOS^[2]

[1] Associate Professor. Hellenic Naval Academy, Sea Sciences and Navigation Laboratory.
Terma Hatzikyriakou Ave. Pireas. TK 18539. Greece.

tel. +30-2106537500, e-mail: palikari@otenet.gr

[2] Professor. National Technical University of Athens, Cartography Laboratory.

9 H. Polytechniou 15780 Zographou Campus. Greece.

tel: +30-210-7722730, fax: +30-210-7722734, e-mail: lysandro@central.ntua.gr

Abstract

The purpose of this paper is twofold: firstly to present the current status and the weaknesses of the standards of the International Maritime Organization (IMO) on the employment of map projections in Electronic Chart Display and Information Systems (ECDIS) and other Electronic Chart Systems (ECS), and secondly to propose specific map projections for use in navigational systems. The paper starts with a brief overview of the IMO performance standards for ECDIS and the corresponding industry practice concerning the use of map projections and the visualization of navigational paths. Seventeen different map projections are evaluated and compared with respect to their fitness for use in the ECDIS/ECS environment. The comparison is supported by specially constructed maps portraying selected loxodromic and orthodromic navigational paths and distortion analysis data. The conducted study shows that improved visual perception is possible through the proper choice among five alternative map projections, depending on the location and the extend of the area portrayed on the chart.

key words: ECDIS, ECS, map projections, visualization, loxodrome, rhumbline, orthodrome, marine navigation

1. THE IMO PERFORMANCE STANDARDS FOR ECDIS AND THE VISUALIZATION OF NAVIGATIONAL PATHS IN TYPICAL ECDIS AND ECS SYSTEMS

Year 1996 marked a historical milestone in the evolution of marine navigation methods through the adoption of a resolution by the International Maritime Organization establishing the performance standards for the Electronic Chart Display and Information Systems (ECDIS) [1]. These performance standards, as they have been revised and updated [2], provide the basis for the automation of traditional methods for “route preparation”, “route planning”, “route execution” and “route monitoring” in contemporary and future navigational systems.

The IMO performance standards for ECDIS [2] as well as the relevant IHO product specifications for Electronic Navigational Charts [3], [4] - that have to be used in ECDIS - cover adequately many aspects of the portrayal of cartographic and navigational information on the screen such as the display of traditional and simplified symbols, setting screen colors depending on prevailing light conditions, choice and adjustment of the amount of the displayed cartographic and navigational information etc [5]. It is surprising though, that the international standards on ECDIS do not provide for specific requirements or recommendations on the employment of specific map projections, or the presentation of navigational paths, except for the following general requirements [2]:

“ ..., “ECDIS should be capable of displaying all chart information necessary for safe and efficient navigation ... originated by, and distributed on the authority of, government-authorized hydrographic offices.”

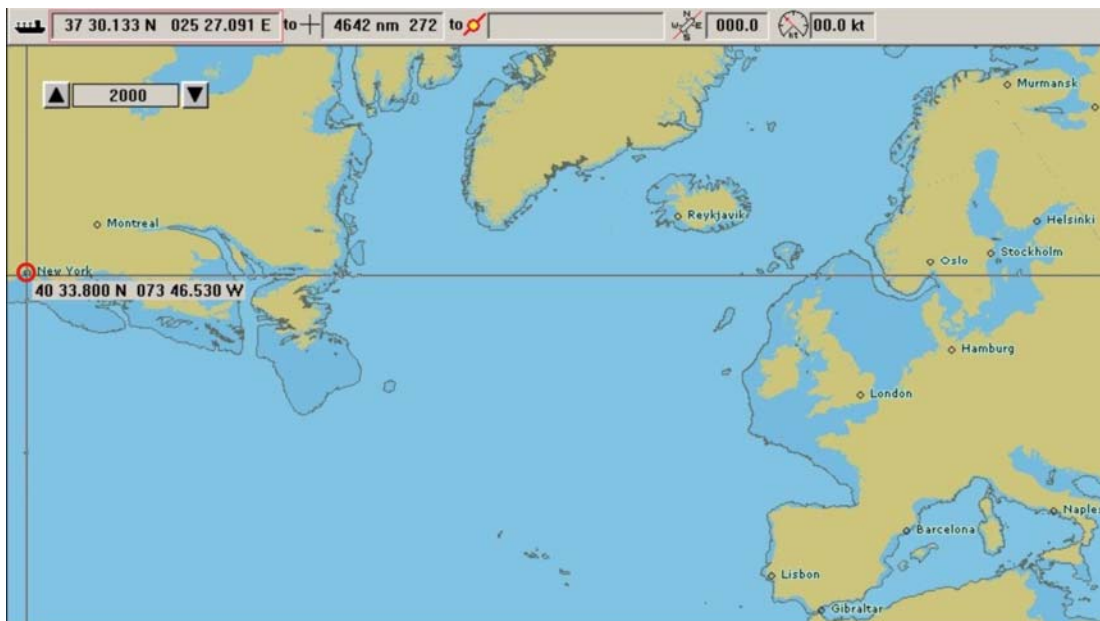
...“It should be possible to carry out route planning including both straight and curved segments”

... “... the selected route and own ship’s position should appear whenever the display covers that area”

In reality the lack of official standardization or recommendations on the use of specific map projections in ECDIS does not cause any real problem on its primary function to contribute to safe navigation. In ECDIS the solution of navigational problems is conducted analytically on the surface of the reference ellipsoid without any graphical work on the surface of the Mercator and Gnomonic projections, as in traditional navigation methods where the Mercator and Gnomonic charts have to be used due to their vital characteristics to portray Rhumb Lines (RLs)/loxodromes, and the Great Circles (GCs)/Orthodromes with straight lines [6]. Consequently in ECDIS as well as in other navigational systems it is not imperative to use particular map projections. Nevertheless the lack of standardization on the

employment of map projections in ECDIS has resulted in the relaxed use of projections in many commercial ECDIS systems that in some cases cause remarkable visual distortions and misinterpretations of the reality, as it is shown in figure 1, where:

- Placing the crosshair (cursor) in succession at the port of New York and the port of London to obtain the geographical coordinates of these two locations, shows that the port of London is quite far north from the port of New York (more than 10 °).
- Observing the position of the horizontal line of the cursor in either of these two points, give the wrong impression that the Port of London is quite far south of the port of New York. This wrong impression is enhanced by the normal practice in commercial ECDIS/ECS systems to not portray the graticule on the electronic charts covering extended geographical areas (i.e. in small scales).



The visual impression is that New York Harbor is north of London harbor, whereas in reality it is south

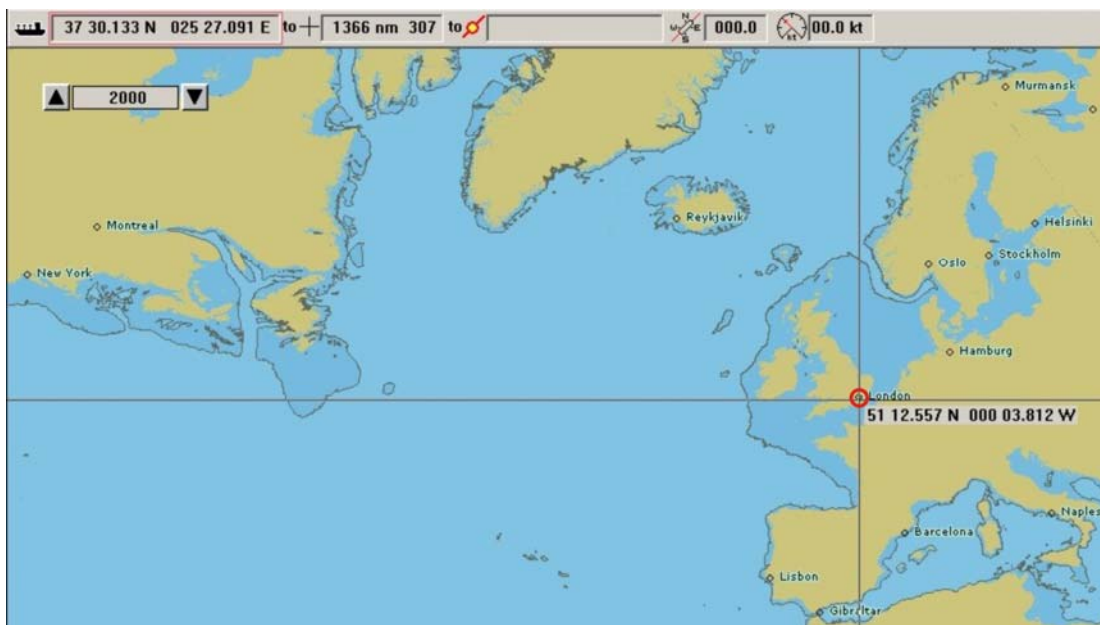


Figure 1: Example of poor visual perception in ECDIS

The choice of the most appropriate map projection in ECDIS/ECS systems should be implemented in accordance with criteria and rules ensuring not only the maintenance of essential characteristics for navigation, but also the control of visual distortions within acceptable limits.

2. CRITERIA AND RULES FOR THE SELECTION OF MAP PROJECTIONS IN ELECTRONIC CHART SYSTEMS

The desired characteristics of the map projections for ECDIS/ECS that have been taken into account in the conducted study are:

- The control of the amount of distortion within acceptable limits (minimization and improvement of the distribution of distortion).
- The form (shape) of Great Circles (GCs) and Rhumb Lines (RLs)/loxodromes
- The form (shape) of the graticule lines

The criterion of minimization and distribution of distortions: The values of all kinds of distortions (linear, area and angular) depend on the scale distortion on the principal directions of the projection [7 pp 63-68]. Since for small values of angular distortion, the values of scale distortion on the principal directions are about the same value, it is sufficient to consider the values of surface distortion [8]. For these reasons, in the process of choosing the most suitable projection in ECDIS/ECS the maximum desired tolerances are set only for the angular and surface distortions. These tolerances are set to 8 ° - 10 ° for angular distortion and to 10% -12% for the area distortion, in order ensure that no serious visual distortion is generated [9 pp295-98].

The criterion of the form (shape) of Great Circles (GCs) and Rhumb Lines (RLs)/loxodromes: For better portrayal of the reality the lines showing Great Circles (GCs) have to be shorter than corresponding Rhumb Lines (RLs)/loxodromes. In addition Great Circles (GCs) should preferably bend towards the equator and Rhumb Lines (RLs)/loxodromes towards the poles.

The criterion of the form (shape) of the graticule lines: In navigational systems it is very useful to ensure that meridians and parallels are portrayed as straight lines, intersected orthogonally. This allows direct conclusions concerning the relative geographic location of any point from the overall visual appearance of the portrayed region. These conclusions do not depend on the portrayal of the parallels and meridians, which also are not always displayed in ECDIS. Thereby there is a risk of creating false impressions, as in the example shown in figure 1.

Realizing that some of the above-mentioned criteria for the selection of map projections cannot be met simultaneously, as in the case of the desired shape of graticule lines, Great Circles (GCs) and Rhumb Lines (RLs)/loxodromes, the evaluation of map projections is conducted through three different approaches. With these three approaches, regardless of the degree of satisfaction of the criteria set, significant improvement of visual perception is achieved.

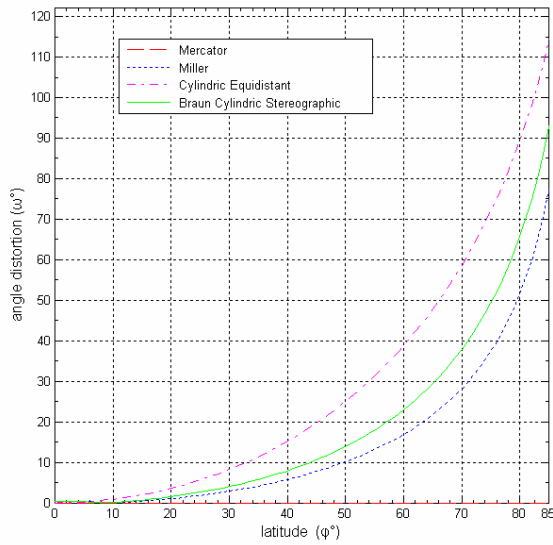
The three different approaches that have been adopted for the evaluation and selection of map projections in ECDIS/ECS systems are:

1st approach: In this approach cylindrical, conical, azimuthal and pseudo cylindrical projections are considered in order to achieve the greatest possible reduction of area and angular distortions and better compromise the conflicting demands for the desired shape of graticule lines, Great Circles (GCs) and Rhumb Lines (RLs)/loxodromes.

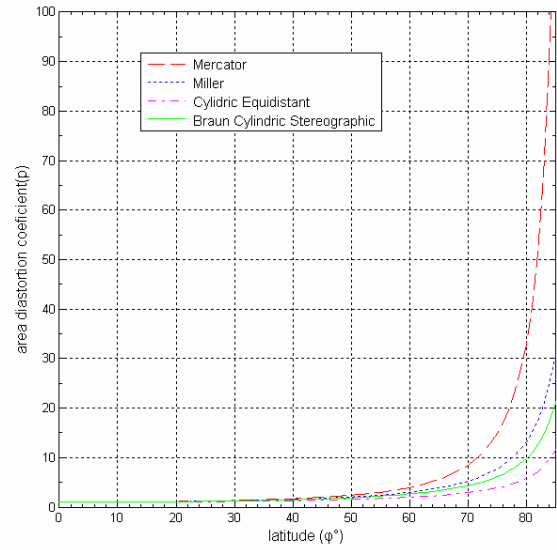
2nd approach: In this approach emphasis is given on the criterion for the desired shape of Great Circles (GCs) and Rhumb Lines (RLs)/loxodromes. The selection is made from the conic and azimuthal family of projections in which Great Circles (GCs) are shown with shorter lines than Rhumb Lines (RLs)/loxodromes. In addition to this feature, these projections have the basic advantage that they reduce significantly the amount of angular and area distortions of the Gnomonic projection used in traditional navigation, as well as the area deformation of the azimuthal stereographic projection, which is used in many ECDIS/ECS systems. In this approach, the compensation cost of ensuring the desired shape of Great Circles (GCs) and Rhumb Lines (RLs)/loxodromes is that the selected projections do not fulfill the criterion for the desired shape of the graticule lines, thus leading to false impressions and conclusions, as in the example in Figure 1.

3rd approach: In this approach emphasis is given on the criterion for the desired shape of the graticule lines. For this reason the selection is made only from the family of cylindrical projections in which meridians and parallels are shown as straight lines intersected orthogonally as in Mercator projection commonly used in traditional navigation. In addition, these projections have the basic advantage over the Mercator projection of the smaller linear distortions whereas the angular distortion is within the specified tolerances. In this approach, the compensation cost of ensuring the desired shape of meridians and parallels, is that the criterion for the shape of Great Circles (GCs) and Rhumb Lines (RLs)/loxodromes cannot be satisfied.

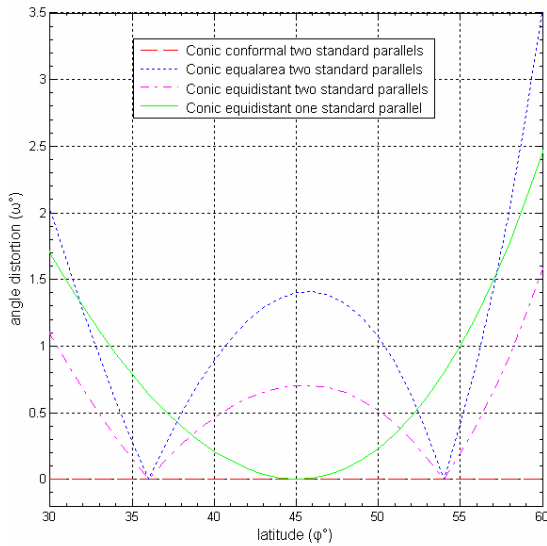
a. Cylindrical Projections: angle distortions



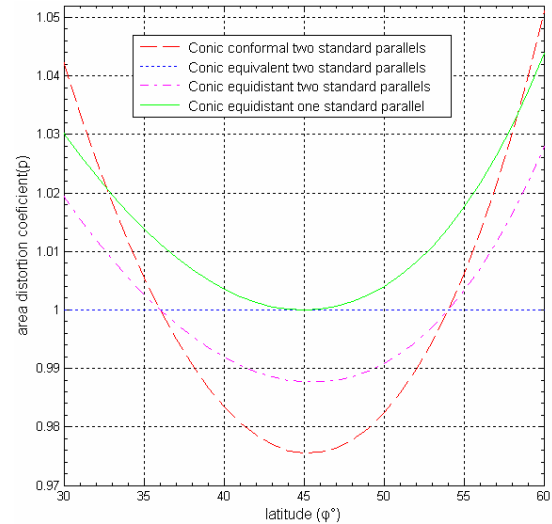
b. Cylindrical Projections: area distortions



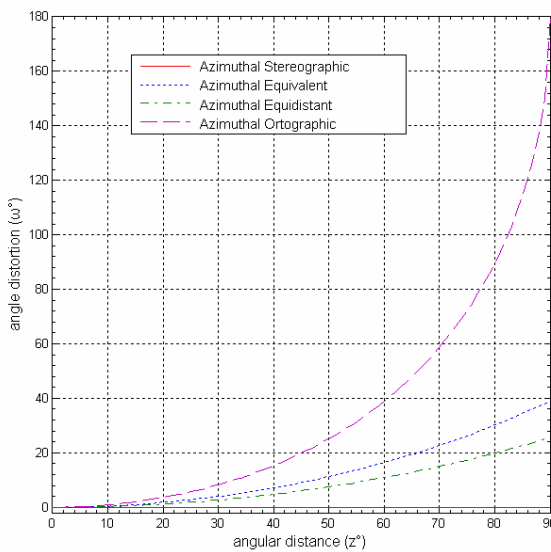
c. Conic Projections: angle distortions



d. Conic Projections: area distortions



e. Azimuthal Projections: angle distortions



f. Azimuthal Projections: area distortions

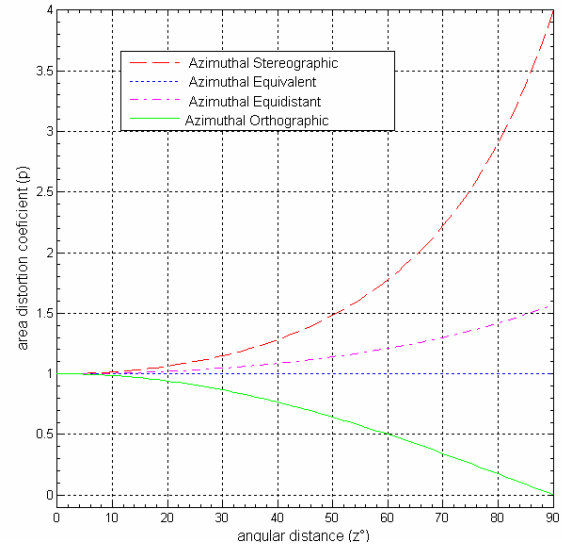
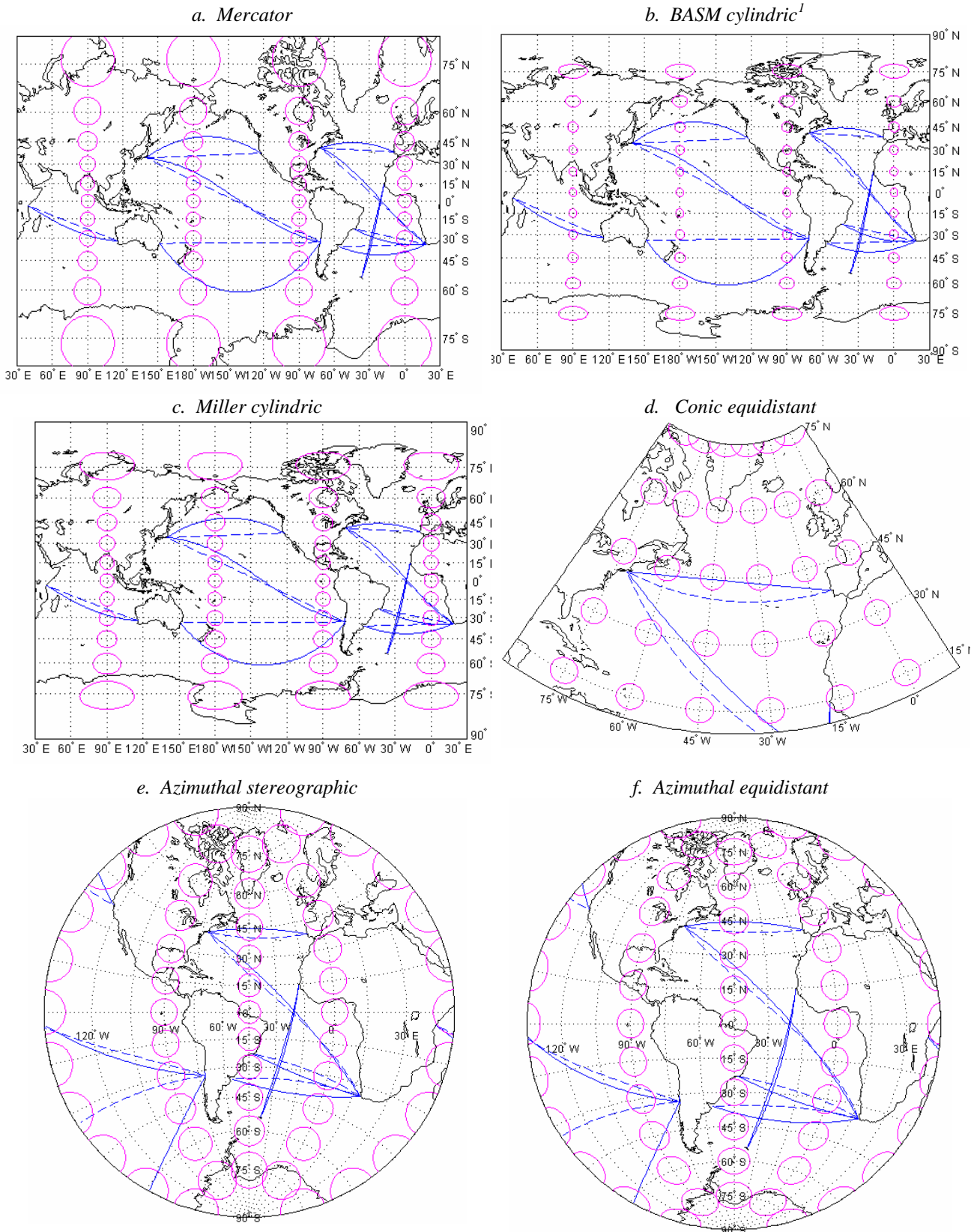


Figure 2. Angle and area distortions in different map projections

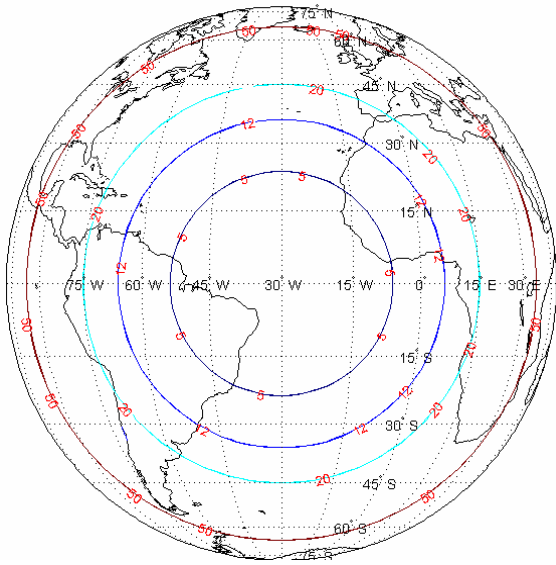


GCs (orthodromes) in solid lines, RLs (loxodromes) in dot lines

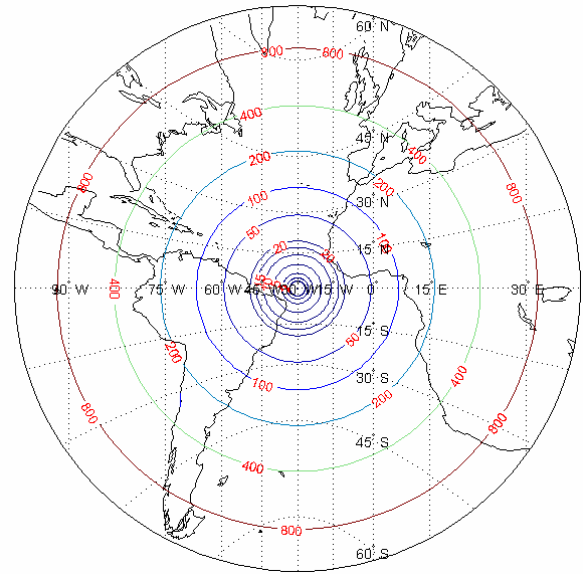
Figure 3. GCs, RLs and distortion ellipses on different map projections

¹ BASM: Bol'soy Sovetskiy Atlas Mira cylindrical projection (cylindrical stereographic at 30°)

a. Azimuthal Orthographic: angular distortion isolines



b. Azimuthal Gnomonic: area distortion isolines



3. EVALUATION OF MAP PROJECTIONS FOR ELECTRONIC CHART SYSTEMS

According to the rules and criteria outlined in Section 2 and the results of the comparative study of the basic characteristics of all kinds of map projections, as they are presented in bibliography [7], [9], [10], the seventeen map projections listed in Table 1 have been selected for further evaluation. The cylindrical projections of table 1 have been selected because they fulfill the criterion for the shape of the graticule lines as in the traditional Mercator projection and at the same time they have moderate distribution of distortion. Analogously the conic and azimuthal projections of Table 1 have been selected for further evaluation because with the appropriate parameterization they fulfill the criterion for the shape of Great Circles (GCs) and Rhumb Lines (RLs)/loxodromes and have better distribution of distortion from those currently used. The pseudocylindrical projections have been selected because they are characterized by moderate distribution of distortion globally and they fulfill even partially the criterion for the shape of the graticule lines since they portray the parallels with parallel straight lines.

The assessment of the projections of Table 1 has been based on:

- The calculation of the angular and area distortions for each projection and the construction of relevant plots such as those shown in figure 2.
- The construction of special maps showing Great Circles (GCs) and Rhumb Lines (RLs)/loxodromes routes and distortion ellipses for each projection such as those shown in figure 3.
- The construction of special maps showing isolines of area and angular distortion for each projection such as those shown in figure 4.

Table 1. Map projections evaluated for potential use in navigational Electronic Chart Systems (ECDIS and ECS)

Cylindric	Conical	Azimuthal	Pseudocylindric
Mercator	Conformal	Conformal	Robinson
Plate Carré	Equidistant	Equidistant	Loximuthal
Cylindric equidistant	Equivalent (equal area)	Equivalent (equal area)	
Miller/Miller modified		Orthographic	
Cylindric Stereographic/Braun		Gnomonic	
Cylindric Sterographic/ Gall			
Cylindric Sterographic /BASM			

The results of the analysis of the abovementioned plots and maps utilizing the three approaches mentioned in section 2 are:

1st approach: For the minimization and improvement of the distribution of all kinds of distortion (linear, area and angular), the optimum map projections should be selected among the Mercator, the BASM Cylindric Stereographic, the Miller modified, the conic equidistant and the azimuthal equidistant projections, depending on the location and the extend of the area portrayed on the screen.

2nd approach: For the optimum portrayal of Great Circles (GCs) and Rhumb Lines (RLs)/loxodromes, the best map projection is the azimuthal equidistant or the conic equidistant, depending on the location and the extend of the area portrayed on the screen

3rd approach: The best map projection for the replacement of Mercator projection, where the latter has significant linear distortion, can be selected between the BASM Cylindric Stereographic and the Miller modified cylindrical projection depending on the location and the extend of the area portrayed on the screen.

4. CONCLUSIONS

The calculation and analysis of the distribution of distortions on seventeen (17) map projections and the comparative study of their features for the support of navigation shows that the use of map projections other than those currently used in ECDIS/ECS systems can provide better visualization results along with considerable reduction of the average magnitude and better distribution of all kinds of distortions. The improved visual perception is possible through the proper choice among five (5) alternative map projections, depending on the location and the extend of the area portrayed on the screen.

REFERENCES

1. IMO [International Maritime Organization]. Resolution MSC. 64(67). *Recommendation on Performance Standards for Electronic Chart Display and Information Systems (ECDIS) Annex 5*, adopted on 4 December 1996.
2. IMO. 2006. *IMO Revised Performance Standards for Electronic Chart Display and Information Systems (ECDIS)*. IMO Resolution MSC 82/24/Add.2/Annex 24 International Maritime Organization, London.
3. IHO S-57: International Hydrographic Organization *Transfer Standard for Digital Hydrographic Data*, Edition 3.1 November 2000.
4. IHO S-100: International Hydrographic Organization *Universal Hydrographic Data Model*, Edition 1.0.0 January 2010.
5. IHO S-52/Ap. 2. 1997. [International Hydrographic Organization. Special Publication No. 52 Appendix 2]. *Colour & Symbols Specifications for ECDIS*. 4th Edition, July 1997.
6. AMN [Admiralty Manual of Navigation] 1987. Vol I. TSO [The Stationary Office]. London.
7. Maling, D. H. (1973): *Coordinate Systems and Map Projections*. George Philip and Son Ltd., 2nd ed., Pergamon Press, Oxford.
8. Delmelle E. 2001. "Map Projection Properties: Considerations for small-scale GIS applications". Master of Arts Thesis. University of New York. Buffalo
9. Bugayevskiy, L. M., Snyder, J. P *Map Projections – A Reference Manual*, Taylor & Francis, London 1995.
10. Snyder, J.P., and P.M. Voxland. 1989. *An album of map projections*. U.S. Geological Survey Professional Paper 1453..